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Oil import portfolio risk and spillover volatility

Simona Bigerna *, Carlo Andrea Bollino, Paolo Polinori

University of Perugia, Department of Economics, Via A. Pascoli, 20, 06123, Perugia, Italy

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ABSTRACT

The concept of energy security has been recently extended to encompass not only the concept of physical supply availability or concerns about the lack of, but also new aspects related to price stability and affordability. Energy security is viewed, in a financial perspective, as a concept of economic convenience of energy supplies, available from a portfolio of partner countries.

This paper analyzes the oil imports structure of four major Asian energy importers: China, Japan, Korea and Taiwan. We measure the total and bilateral volatility spillovers of the portfolio risk associated with the composition of the main oil suppliers, using forecast-error variance decompositions derived from a vector autoregressive model. Results show that the composition of oil import composition determines varying risk levels for given oil import growth rates and average import prices and before and after the Financial Crisis of 2008. We simulate two shocks: Covid-19 Scenario and Increased imports from KSA, showing that risk increases within a 3–15% range. As expected, spillover effects are increasing and exhibit a consistent reallocation effects, confirming that a deep shock can modify the quality composition of the variance and not only its level.

1. Introduction

Over the past 40 years, the concept of energy security has changed as a result of numerous social, economic and political changes affecting both oil producer and importing countries. The evolution of this important concept has taken place in different ways in the world providing various definitions of safety and taking into account different types of energy sources.

Chronologically the most representative events for the evolution of the concept of energy security were the energy crisis of the 70s that have highlighted the importance of the security of the energy physical supply; the extreme volatility of oil prices after the First Gulf War that have underlined the central role of the prices affordability; the World Trade Center disaster in 2001 that have reaffirmed the centrality of the geopolitical dimension in the energy dependence and finally the G8 summit in 2006 that discussed a plan of action for "global energy security" focusing on the sustainable development. Summarizing, the concept of energy security has been enriched in economic analysis in occasion of several world crises events. Furthermore, the worldwide progressive expansion of the energy demand and of the renewable energy sources have supported the chronological evolution of energy security toward a multi-pillar concept including the security of physical supply, the issues of price affordability, market and geopolitical stability, the infrastructure development, the energy efficiency, and the environmental impact and societal effects.

According to this conceptual evolution, among others institutions, the International Energy Agency (IEA, 2020) defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance.

This last characteristic has been stressed in 2020 given that the pandemic due to the Covid-19 is determining the biggest worldwide global crisis affecting all sectors such as transport, trade and industrial activities with severe impacts on the energy sector.

The Global Energy Review 2020 points out countries are experiencing an average drop in energy demand per week ranging from 18% to 25% and despite the existence of consolidated institutions (among others international trade platforms and strategic petroleum reserves) an unprecedented fluctuation has shaken up the global oil market.

The lesson learned from the recent negative price shock in the future West Texas Intermediate market, occurred on April 20, 2020 (Financial Times, 2020), is clear: when ordinate market participation and market thickness is weakened or halted, then the market volatility increases, i.e.

* Corresponding author.
E-mail address: simona.bigerna@unipg.it (S. Bigerna).

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market risk increases.

Higher fungibility of energy sources and individual fuels, increasing connectivity of regional fuel markets and rapid deployment of renewables presumably reduce the pressure to secure physical fuels supplies and facilitate reliance on market mechanisms (Brown et al., 2014). Energy security as insurance measures tools to reduce the risks of disruptions in energy imports at reasonable prices is the most widespread interpretation (Lesbirel, 2004; Dorian et al., 2006; Vivoda, 2009). Indeed, an appropriate portfolio of oil imports aims to minimize risk exposure of disruption in energy imports to ensure a sustainable also allow to control importing costs at an appropriate level (Li et al., 2014). A new energy security assessment framework is needed to capture the trade-offs between the supply security and price affordability components, associated risks and potential vulnerabilities, as well as the individual characteristics of entire regions of the world. For example, Intriligator (2015, p. 221) highlights that: *"In terms of pure economics, the outlook for energy security in the Asia-Pacific region looks particularly troubling, with rising levels of oil and coal consumption and a very strong rise in demand for other energy imports especially with the impact on climate".*

Our approach is based on the economic evaluation of the energy security of a given country, considering a two-dimensional measure, associated to the risk and return of a given portfolio of oil suppliers. In other words, a country faces a portfolio of suppliers to satisfy her energy needs and the composition of this portfolio can be decided choosing an optimal risk-return combination. Empirically, we apply this approach using data for four major Asian oil importers: China, Japan, Korea and Taiwan.

This paper contributes to the literature in three ways. First, using the portfolio approach, we estimate a risk-return frontier, in order to assess the minimum risk attainable and its associated return. We compare the theoretical minimum risk with the historical data, to show empirically the amount of risk that a country has accepted to satisfy her energy requirements. In this context, we have used two empirical measures of the return: the total imports growth rate and the average import price. Both can be considered an empirical measure of the return of the oil import portfolio. The associated risks are represented by the variance of the growth rates of imports from the suppliers and the variance of the individual suppliers' import prices, respectively.

Second, we use a vector autoregressive model to recover from forecast-error variance decompositions a measure of total and bilateral volatility spillovers. We use Diebol and Yilmaz (2012) methodology to measure total and bilateral spillovers across different suppliers from the perspective of the importing country. In this way it is possible to take into account how each importing countries considers its trading partners and the relevance of the bilateral relationships to determine the overall portfolio volatility and then what are the consequences for the portfolio choice of imports.

Third, we design and simulate two scenarios aimed at assessing the potential impacts on the importers' portfolios resulting from the changes in portfolio structure, geopolitical events and disruptions due to the pandemic crisis. We analyze the effects due to changes in the oil import decisions of a large importer and the effects due to changes in the supply of a large exporter, in terms of changes in volatilities and then we analyze the changes in the spillover effects.

The paper is organized as follows. Section 2 gives a brief review of the literature on energy security. Section 3 the estimation methodology and the data utilized in this paper are briefly interpreted. Section 4 summarizes the empirical results and Section 5 presents our conclusions.

2. Literature review

Energy security is a multidimensional concept that mainly refers to four characteristics:

1. The physical availability and accessibility of supply sources;
2. The economic affordability;
3. The long-term environmental sustainability;
4. The geopolitical dimension.

The construction of the multi-pillar dimension of the energy security concept has distant origins that date back to the first energy crises of the 1970s (Willrich, 1976). From those years, energy security has been associated to the supply availability assuming only the point of view of the fuel-importing countries. Security and vulnerability are the main keys to understanding the worldwide energy scenario and the link between energy security and energy vulnerability was the certainty of the physical energy provision for the importing countries.

The second important step in the evolution of the concept of energy security has been the First Gulf War which caused a strong volatility of oil prices. Starting from the 90s the characteristic of the "physical supply" was flanked by the central role of the price's affordability. Price instability led scholars to extend towards the concept of energy security including the aspects of economic accessibility of energy and its impact on national well-being. Literature suggested that the energy security concept should embrace an extensive list of issues including infrastructure (Scheepers et al., 2007), and energy efficiency (Hughes, 2009).

In 2001 the World Trade Center disaster extends the security concept affirming the centrality of the geopolitical dimension in the energy dependence (Huntington and Brown, 2004). In particular the growing fears about the stability of the world's energy resources has highlighted the possibility to reduce energy vulnerability deploying domestic energy sources. This option becomes a real option with the worldwide diffusion of the renewable energy sources. Policymakers understood that it is possible to merge security concerns into the climate change policies promoting the fourth and last step. Indeed, the G8 summit in 2006 discussed a plan of action for "global energy security" focusing on the sustainable development and integrating energy security and environmental concerns.

Focusing on the institutions until the 2014 the IEA (2014) definition only included the first two characteristics does not take into account the others two. These last two dimensions were instead assumed as crucial by the Asia Pacific Energy Research Center (APERC, 2007) and by European Commission (EC, 2000) that in their definition explicitly refer to the sustainable development and to the respect of the environmental concerns.

Scientific research has accompanied this path with many scholars that have underlined these and others aspect linked to the energy security such as environmental impact (Greenleaf et al., 2009; Radovanović et al., 2017), societal effects (Kemmler and Spreng, 2007; Wang et al., 2019), governance (Yergin, 2006; Bhattacharyya, 2011; Ji et al., 2019), risk with extreme events (Li et al., 2014) and uncertainty (Maghyereh et al., 2019).

All in all, security of physical supply and price affordability remain the principal components of the energy security paradigm also in the perspective of major international organizations (IEA, 2018, 2019; European Commission, 2000; UNDP, 2000).

Nevertheless, several other authors provide definitions centered on geopolitical and governmental dimensions. For example, Willrich (1976, p. 67) assert that energy security refers to the *"assurance of sufficient energy supplies to permit the national economy to function in a politically acceptable manner"*. Hughes (2006) underlines the importance of the governmental actions and policies that ensure a community has access to reliable and secure sources of energy at a reasonable price.

Today, energy security is a comprehensive term that covers many concerns linking energy, economic growth, and political power. Energy security perspective assumes different means according to different position in the value chain. Reasonably priced energy on demand and worry about disruptions are required by end users. Revenue and demand security are at the heart of the energy security concept for major oil producing countries. Access to new reserves and ability to develop new infrastructure, and stable investment regimes are demanded by oil and gas companies to ensuring energy security. Finally, potential causes of service interruption are crucial for policy makers. Infrastructure problems, terrorist attacks, geopolitical crises, strategic reserves and amount of excess capacity are fundamental characteristics (Nuttall and Manz, 2008).

In this paper we analyze the structure of each oil importer, considering that the exporting sources of oil are viewed as a portfolio of different supplier. We assume that the variability across suppliers constitutes a risk to be managed in order to obtain a desired level of supply. Obviously, the higher the quantity requirement, i.e. the higher the oil import growth rate, the higher is the variability of the supplying partners, i.e. the higher is the associated risk.

In this context, the concept of energy security (Stringer, 2008) means defining a framework that allows the main stakeholders, both to assess the risks associated with agreements between countries, and to appropriately correct any contractual incompleteness. Consequently, diversification plays an important role in both contexts. Helm (2002) argues that the natural way to think about diversification is as a portfolio effect. Risks are spread in financial markets by diversification, and so, too, by diversifying fuel sources. This analysis provides empirical measurement and development of appropriate indices. Indeed, several scholars have quantified oil supply risks, with diversification of import sources as one of the variables, based on risk-assessment models; always, diversification was quantified by using some kind of scientific measures of diversity.

Diversification policy allows oil importers both to reduce portfolio risks and to contextualize the strategy of diversification of oil imports in a general security energy policy framework (Vivoda, 2009). More incisive and verifiable energy policies could be obtained by using multi-faceted energy security indicators. The aspects analyzed to extend the concept of energy security concern, for example, the diversification of supply sources and the distance between the source of supplies and the point of consumption (Cohen et al., 2011).

Another important aspect is the interaction between the exporting countries and energy security. Geographical diversification of imports is one of the strategies for improving energy security in oil-importing countries (Vivoda, 2009). The interdependence of volatility of country risk between different countries is analytically comparable to the volatility spillovers in the financial literature and to the concept of dynamic correlation both symmetric and asymmetric. The asymmetric spillover effects of volatility between oil market and stock markets have been extensively analyzed, among others, by Li et al. (2009), Khalfaoui et al. (2019) and Sarwar et al. (2019). From a macroeconomic perspective, Nasir et al. (2019) analyzed the impact of oil price shocks on the economies of oil exporting countries, which could potentially feedback on the capability to ensure security of supply in the global market. Microeconomics and operations research perspectives mainly focus on energy security address the issue of risk minimization assessment, given the risks are known and quantifiable. For example, Zhang et al. (2017) developed a model to optimize China's LNG imports simulating the effects of changes in input factors and extreme events. EIA (2017) and Rioux et al. (2019), among others, analyze the interactions of the energy imports security with both the domestic energy systems and the global fuel markets. Political science perspective deals with energy security taking into account stakeholders' behavior in the bargaining process and the distribution of power among them (Garrison, 2010; Hughes and Lipscy, 2013). Our proposed method, based on financial analysis, assesses appropriately the trade-off between price and physical supply security components, using the portfolio approach to take into account spillover effects. Spillover effects are externalities, i.e. effects of an economic activity or process on those who are not directly involved in it. Similarly, dynamic correlations between country risks of different countries also present asymmetric characteristics (Li et al., 2009). This is crucial from oil importing countries point of views given that if shocks affect oil suppliers in portfolio this determine a more critical situation for importing country.

3. Theoretical model and estimation

The theoretical model is applied to four major East Asian countries: China, Japan, Korea and Taiwan, representing the strategy to minimize the risk associated to an expected return. In other words, a country decides the composition of a portfolio of oil suppliers, considering simultaneously the growth rate of imports and the associated variability of the growth rate. In addition, we assume that a country considers the average import price (the lower the price, the higher the benefit) of a portfolio of suppliers and the associated variability of the individual suppliers' prices. We note that the in the literature, portfolio theory has been applied to explore the impact of the oil price on the financial markets and the stock markets (recent examples are: Shahzad et al. (2018); Lang and Auer (2019); Tissaou and Azibi (2019)). Recently, Bigerna et al. (2020) applied the portfolio theory to oil imports of major Asian countries. In this paper we used their data to facilitate the comparison of the empirical results. Other applications of the portfolio theory to the industrial diversification of the economic structure can be found in Chandra (2003), Bigerna (2013), Kluge (2017), Hafner (2019) and Malkina (2019).

3.1. Portfolio risk minimization

The notion of return of oil imports is grounded on the idea that energy is an essential input in the aggregate production function of GDP, i. e. there exists an optimal derived factor demand for energy: $E = f(GDP)$. The desired or optimal growth rate of GDP implies a desired growth rate of energy demand, E, to be satisfied with import an import portfolio from different n suppliers: $E = g(E_1, E_2, \ldots, E_n)$. Therefore, the return is the overall oil import growth rate, h^*, computed as the monthly growth rate in oil import volumes and the uncertainty is the variability of the import growth rate across suppliers:

$$h^* = (E - E_{-1}) / E_{-1} = \sum_j s_j[(E - E_{-1})/E_{-1}]_j \tag{1}$$

Alternatively, we can consider the return as the benefit of getting a low price for the oil imports:

$p_b^* = p^*(p_1, p_2, \ldots, p_n)$. In this case, we measure the return of this benefit P_b^* as the lowest oil price possibly attainable in the world market. This is a function of the import composition of the different n prices of the n suppliers. Operationally, we take un upper bound from the historical values of the oil price and compute $p_b^* = (P - p)$ where P is the upper bound ($1000/ton) ad p is the historical average price. In view of these assumptions, the standard portfolio optimization theory prescribes to minimize the weighted average of covariance matrix of the individual inputs:

$$v = \sum_i \sum_j s_i s_j v_{ij} \tag{2}$$

where v is the square root of the return's covariance matrix and s_i is the *i-th* import shares, given the constraint of the optimal return rate of *i*-th economy Θ_i^*. This latter is the return with weight reflecting the shares of the suppliers in the portfolio:

$$\Theta_i^* = \sum_j s_j \Theta_j^* \tag{3}$$

The minimization yields the efficient combinations of return and its minimum, i.e., a frontier suitable for empirical estimation, as follows:

$$SD_t = \alpha + \beta_1 \Theta_t + \beta_2 \Theta_t^2 + e_t \tag{4}$$

In eq (4) we can consider $\Theta_t = h^*$ and $\Theta_t = p_b^*$, the annual growth rate of oil imports or the average benefit, respectively. Consequently, SD_t is the associated standard deviation.

The coefficients are the fixed effect α and the frontier convexity β_1

and β_2 parameters and the residual error e_t.

Next, we assume a VAR structure for each country to estimate the dynamic response of the return to the shocks of the main suppliers. The VAR specification for each country j considers the oil import growth (and the price benefit) for main five suppliers:

$$\begin{aligned}[\Theta_{j1},\ \Theta_{j2},\ \Theta_{j3},\ \Theta_{j4},\ \Theta_{j5}] = {} & \phi_{j1}[\Theta_{j1},\ \Theta_{j2},\ \Theta_{j3},\ \Theta_{j4},\ \Theta_{j5}]_{t-1} \\ & + \phi_{j2}[\Theta_{j1},\ \Theta_{j2},\ \Theta_{j3},\ \Theta_{j4},\ \Theta_{j5}]_{t-2} \\ & + \ldots .. + \phi_{j5}[\Theta_{j1},\ \Theta_{j2},\ \Theta_{j3},\ \Theta_{j4},\ \Theta_{j5}]_{t-5}\end{aligned} \tag{5}$$

Where, as before $\Theta_{jkt} = h_{kj}$ and $\Theta_{jkt} = p_{kj}$; h_{kj} is the growth rate of the *k-th* supplier to country *j* and p_{kj} is the price benefit from the *k-th* supplier to country *j*.

3.2. Volatility spillover effects

Volatility spillovers across different markets, in the context of the global world oil market are an interesting feature to analyze in the context of the recent global shock due to lockdown of economic activities induced by the Covid-19. While this analysis has been used in stock markets, the volatility spillovers in oil markets have not yet been analyzed in the framework of volatility interdependence of suppliers' portfolio. There is some analysis of the price volatility spillover between oil market and stock markets and agricultural markets (Nazlioglu et al., 2013; Ewing and Malik, 2016; Zhang et al., 2020). We investigate the interdependence of the volatility spread among countries and we measure it constructing a summary volatility spillover index.

Our spillover index is based on the forecast error variance decomposition (FEVD) for a VAR model at h-step ahead forecast, and we construct it using both the orthogonalized FEVD and the generalized FEVD. We are not interested in distinguishing contagion from interdependence, but our methodology is designed to provide a toolkit to measure the proportion of a shock from one country that spills over to another country or group of countries. This analysis is useful when a policy-maker is willing to know what country (or group of countries) is more vulnerable when another country is hit by a crisis (Urbina, 2013).

Using a generalized vector autoregressive framework in which forecast-error variance decompositions are invariant to the variable ordering, we propose measures of both the total and directional volatility spillovers (Diebold and Yilmaz, 2012, 2014). Operationally, we extend the spillover index associated with an N-variable simple vector autoregression (VAR), which is order-dependent given by the Cholesky factor orthogonalization), to a measure of the directional spillovers derived from a generalized VAR framework that eliminates the possible order dependence.

Lets $x_t = \sum_{i=1}^{p} \phi_i x_{t-1} + \varepsilon_t$ a covariance stationary N-variable VAR(p), where $\varepsilon_t \sim (0,\ \Sigma)$ is a vector of independently and identically distributed disturbances and $x_t = \sum_{i=0}^{\infty} \phi A_i \varepsilon_{t-1}$ is the moving average representation with the *NxN* coefficient matrices and A_i obey the recursion: $A_i = \phi_1 A x_{i-1} + \phi_2 A x_{i-2} + \ldots + \phi_p A x_{i-p}$ with A_0 being an *NxN* identity matrix and with $A_i = 0$ for $i < 0$.

Variance decompositions is a useful tool to analyze and decompose the forecast error variances of each variable according to the various system shocks, indeed it allow us to assess the fraction of the H- step-ahead error variance in forecasting x_i that is due to shocks to x_j, $\forall\, j \neq i$, for each i.

Variance decompositions calculation based on Cholesky is affected by the well known ordering problem that can be circumvent, computing all possible ordering and averaging the decomposition across different ordering.

3.2.1. Variance shares

Given some shocks to x_i, for $i = 1, 2, \ldots, N$, and to x_j, for $i,j = 1, 2, \ldots, N$, $(i \neq j)$, we distinguish own and cross variance share as the fractions of the H-step-ahead error variances in forecasting x_i that are due to its own shock and that du to shocks to other variables (spillover), respectively.

The KPPS H-step-ahead forecast error variance decompositions is labeled $\theta^g_{ij}(H)$, for H = 1, 2, … N, so that we can define:

$$\theta^g_{ij}(H) = \frac{\sigma_{jj}^{-1}\sum_{h=0}^{H-1}\left(e_i' A_h \sum e_j\right)^2}{\sum_{h=0}^{H-1}\left(e_j' A_h \sum A_h' e_i\right)} \tag{6}$$

where Σ is the variance matrix for the error vector ε, σ_{jj} is the standard deviation of the error term for the *j*th equation, and e_i is the usual selection vector.

The index in (5) is normalized as:

$$\widetilde{\theta}^g_{ij}(H) = \frac{\theta^g_{ij}(H)}{\sum_{i,j=1}^{N}\theta^g_{ij}(H)} \tag{7}$$

3.2.2. Total spillovers

The total volatility spillover index (TSI) is defined as:

$$S^g(H) = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N}\widetilde{\theta}^g_{ij}(H)}{\sum_{i,j=1}^{N}\widetilde{\theta}^g_{ij}(H)}\cdot 100 = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N}\widetilde{\theta}^g_{ij}(H)}{N}\cdot 100 \tag{8}$$

using eq (6) and noting that this is similar to the measure proposed by Diebold and Yilmaz (2009). The TSI measures the contribution to the total forecast error variance of spillovers of volatility shocks in each importing country across the portfolio of oil suppliers.

3.2.3. Directional spillovers

In order to capture the direction of volatility spillovers across the portfolio of oil suppliers (and not only the total volatility spillover intensity), we use a generalized VAR approach, which yields impulse responses and variance decompositions invariant to the variables ordering. The directional volatility spillovers have two directions: spillover received by market *i* from all other markets *j* and spillover transmitted by market *i* to all other markets *j*.

The two measures are:

$$S^g_{i.}(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N}\widetilde{\theta}^g_{ij}(H)}{\sum_{i,j=1}^{N}\widetilde{\theta}^g_{ij}(H)}\cdot 100 = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N}\widetilde{\theta}^g_{ij}(H)}{N}\cdot 100 \tag{9}$$

and

$$S^g_{.i}(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N}\widetilde{\theta}^g_{ji}(H)}{\sum_{i,j=1}^{N}\widetilde{\theta}^g_{ji}(H)}\cdot 100 = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N}\widetilde{\theta}^g_{ji}(H)}{N}\cdot 100 \tag{10}$$

The measure in eq (8) captures the decomposition of the total spillover received from and the measure in eq (9) captures the decomposition of the total spillover transmitted to any given source, respectively.

3.2.4. Net spillovers and bilateral spillover

Using the previous definitions, it is straightforward to compute the net effect as the difference between the volatility received and transmitted.

This is defined as the net volatility spillover from market *i* to all other markets *j*

$$S^g_i = S^g_{.i}(H) - S^g_{i.}(H) \tag{11}$$

Finally, we can define the bilateral volatility spillover as the difference between the volatility shocks transmitted from supplier *i* to supplier *j* and those transmitted from *j* to *i*

$$S_{ij}^{g}(H)=\left(\frac{\widetilde{\theta}_{ji}^{g}(H)}{\sum_{i,k=1}^{N}\widetilde{\theta}_{i,k}^{g}(H)}-\frac{\widetilde{\theta}_{ij}^{g}(H)}{\sum_{j,k=1}^{N}\widetilde{\theta}_{j,k}^{g}(H)}\right)\cdot 100=\left(\frac{\widetilde{\theta}_{ji}^{g}(H)-\widetilde{\theta}_{ij}^{g}(H)}{N}\right)\cdot 100 \quad (12)$$

4. Results and discussion

4.1. Estimation of the frontiers

Monthly oil imports are recorded in physical terms (tons) and value terms ($/ton CIF). Monthly average unit price are recovered from the ratio of associated imported values to quantities.

Data are spanning for the period T (generally 2002–2017) recording a certain number of suppliers S.[1] For each supply source, monthly growth rates of flows in physical terms and a monthly measure of price benefit, defined as $1000 minus the unit price are computed, together with the associated standard deviations.

We assume normal distribution of the returns, agents' rationality and risk adverse preferences, price-taking behavior and no borrowing constraints to support the model of efficient portfolio determination of each country's oil importing strategy. In particular, we maintain that an economy relying on oil supplies does not adopt irrational and speculative behaviors and it is price taker in the international oil market.

Cointegrating properties of the growth returns and price benefit for the four economies are checked with the Dickey-Fuller and the Engle-Granger tests, showing that the growth variables are generally stationary and that cointegration relations exist (Table 1).

The empirical estimation is replicating the results of Bigerna et al. (2020). We recall that the estimation allows to construct the corresponding frontier slopes for different levels of return and risk.

We show the risk minimizing rates of growth of imports and of the price benefit together with the associated level of risk and we confront it with the historical value of the last year of the sample 2017, which is used as a baseline for the scenario simulations below (Table 2a and 2b).

Note that the historical values of growth rates in 2017 are lower than the estimated optimal import growth rate values for all countries. In addition, we note that the historical values of price benefit in 2017 are higher than the risk minimizing levels for all countries. This implies that in 2017 all countries have adopted a cautious attitude in the import strategy and gained a substantial price benefit. Focusing on the variability of the estimated value, we observe that the standard deviations are lower than the optimal values for given growth rate, confirming the production reduction among countries analyzed. In the same period importing oil price exhibits a higher volatility, if compared to the optimal values, suggesting the existence of several price behaviors among exporting countries.

We show the VAR estimations (Table 3a and 3b). The VAR specification is slightly different for each country because we have chosen the main suppliers for each. The main suppliers in the VAR for each country are listed in column 2 of the tables. We can see that only Saudi exports oil for all importing countries analyzed exhibit a significant impact. Also, for the other countries results confirm that the main diagnostics of the estimation are satisfactory.

We also show the Forecast error variance decomposition (FEVD) in Table 4a and 4b.

We note that the future uncertainty due to shocks is dominated generally by the own variance. In the case of oil import growth rate, the own Saudi Arabia value is lower than that for other suppliers. The opposite occurs in the case of oil price benefit.

Table 1
Cointegration analysis.

Engle-Granger test	TestStat	P-value	Num.lags
China			
Oil import growth rate	−4.49307	0.0172	5
Oil price benefit	−6.49644	0.0000	2
Korea			
Oil import growth rate	−5.78186	0.0001	2
Oil price benefit	−5.54518	0.0003	2
Japan			
Oil import growth rate	−5.98774	0.0001	5
Oil price benefit	−5.45109	0.0005	4
Taiwan			
Oil import growth rate	−6.49044	0.0001	2
Oil price benefit	−6.39239	0.0001	2

Table 2a
Estimates of optimal and historical (2017) growth rate of oil imports.

Importer	Optimal Oil Imports Growth Rate %	Minimum std dev	Historical 2017 oil imports growth rate %	Historical 2017 std dev of oil imports
China	1.43	0.061	1.22	0.055
Japan	2.01	0.68	1.17	0.67
Korea	1.00	0.09	0.26	0.53
Taiwan	1.59	0.85	1.1	0.79

Table 2b
Estimates of optimal and historical (2017) price benefit of oil imports.

Importer	Optimal Price Benefit ($/ton.)	Minimum std dev	Historical 2017 oil price benefit	Historical 2017 std dev of oil price benefit
China	452	275	651	352
Korea	335	239	599	262
Japan	359	388	597	415
Taiwan	390	270	610	272

Table 3a
VAR estimation results – growth rate of oil imports.

Country	Equations	Log L	R squared	Mean dep var	Regression SE	DW
Taiwan		1359.5				
	Saudi		0.50	0.28	0.11	2.2
	UAE		0.21	0.06	0.04	2.1
	Oman		0.28	0.05	0.05	2.1
	Iraq		0.16	0.056	0.06	1.9
	Iran		0.54	0.07	0.06	2.1
China		1740.5				
	Russia		0.60	0.10	0.02	2.3
	Saudi		0.41	0.18	0.03	2.1
	Angola		0.25	0.14	0.03	2.0
	Iran		0.38	0.10	0.02	2.2
	Iraq		0.74	0.051	0.02	2.5
Japan		2662.4				
	Saudi		0.76	0.32	0.03	2.2
	Qatar		0.39	0.10	0.02	2.2
	Kuwait		0.23	0.08	0.01	2.1
	Indonesia		0.50	0.03	0.01	2.2
	Iran		0.70	0.09	0.2	2.6
Korea		707.1				
	Saudi		0.37	0.33	0.06	2.3
	Iraq		0.10	0.11	0.07	2.1
	Kuwait		0.9	0.15	0.05	1.95
	UAE		0.1	0.11	0.06	2.0

[1] The period is different for each country, due to data availability: the initial period is 2005/01 for China, 2002/01 for Japan and Korea, 2006/01 for Taiwan. The end period is 2017/12 for all countries the number of suppliers is: $S_{China} = 76$; $S_{Japan} = 51$; $S_{Korea} = 23$; $S_{Taiwan} = 39$.

Table 3b
VAR estimation results – price benefit of oil imports.

Country	Equations	Log L	R squared	Mean dep var	Regression SE	DW
Taiwan		−3352.8				
	Saudi		0.97	57.1	2.9	1.27
	UAE		0.97	58.2	3.8	1.50
	Oman		0.97	57.1	3.4	1.70
	Iraq		0.96	54.7	3.5	1.67
	Iran		0.96	57.7	3.9	1.44
China		−2854.3				
	Russia		0.92	43.9	8.5	2.11
	Saudi		0.84	73.4	13.4	2.01
	Angola		0.78	59.5	13.6	1.95
	Iraq		0.86	23.2	8.8	2.41
	Iran		0.80	42.9	11	2.21
Japan		−3587.4				
	Saudi		0.95	154	8.2	2.22
	Qatar		0.87	46.7	8.9	2.11
	Kuwait		0.80	41.8	9.5	1.95
	Indonesia		0.84	13.5	3.9	2.12
	Iran		0.88	55.5	14.3	2.33
Korea		−2119.6				
	Saudi		0.99	39.9	10.8	1.96
	Iraq		0.98	43.5	15.8	1.85
	Kuwait		0.96	51.7	22.7	2.14
	UAE		0.99	36.3	7.9	1.70

Table 4a
FEVD estimation results – growth rate of oil imports.

Country	Equations					
Taiwan		Saudi	UAE	Oman	Iraq	Iran
	Saudi	76	1	1	1	21
	UAE	1	88	1	1	9
	Oman	1	3	81	1	14
	Iraq	1	1	1	96	1
	Iran	2	1	3	1	93
China		Russia	Saudi	Angola	Iran	Iraq
	Russia	80	8	2	3	6
	Saudi	24	65	3	6	2
	Angola	7	1	83	2	6
	Iran	5	1	5	76	13
	Iraq	7	3	1	2	87
Japan		Saudi	Qatar	Kuwait	Indonesia	Iran
	Saudi	52	8	5	11	24
	Qatar	1	94	2	1	2
	Kuwait	1	1	95	1	2
	Indonesia	3	1	1	94	1
	Iran	2	1	1	1	95
Korea		Saudi	Iraq	Kuwait	UAE	
	Saudi	97	1	1	1	
	Iraq	12	85	1	2	
	Kuwait	4	9	86	1	
	UAE	2	21	3	74	

4.2. *Estimation of the spillover effects*

We report in Tables 5–10 the volatility spillover measures. Its ij_{th} entry is the estimated contribution to the forecast error variance of market *i* coming from innovations to market *j*. All of the results are based on vector autoregressions of order 1 and generalized variance decompositions of 12-month-ahead volatility forecast errors. To check for the sensitivity of the results to the choice of the order of the VAR, we calculate the spillover index for all ordering combinations and for 12 to18 periods ahead. Similarly, we calculated the spillover index for forecast horizons varying from 3 to 12 months. Both measures of total spillover are not sensitive to the choice of the order of the VAR or the choice of the forecast horizon. Hence, the off-diagonal column sums labeled contributions to others (D to O) and row sums labeled contributions from others (D from o) are the "to" and "from" directional spillovers, and the "from minus to" differences are the net volatility spillovers. In addition, the TSI appears in the lower right corner of the spillover table. It is approximately the grand off-diagonal column sum (or row sum) relative to the grand column sum including diagonals (or row sum including diagonals), expressed as a percentage. The volatility spillover table provides an approximate "input–output" decomposition of the total volatility spillover index.

Consider first what we learn from the tables about directional spillovers (gross and net). From the "directional to others" row, we can see that gross directional volatility spillovers to others from each of the four markets are quite different. We can also see from the "directional from others" column that the gross directional volatility spillovers from others to the bond market is relatively large and vary across the countries considered.

Finally, we consider the total (non-directional) volatility spillover, which is effectively a distillation of the various directional volatility spillovers into a single index. The total volatility spillover appears in the lower right corner of following tables, indicating, on average across our entire sample, the percentage of volatility forecast error variance in all

Table 4b
FEVD estimation results – price benefit of oil imports.

Country	Equations					
Taiwan		Saudi	UAE	Oman	Iraq	Iran
	Saudi	95	2	1	1	1
	UAE	72	22	1	1	4
	Oman	27	2	69	1	1
	Iraq	48	5	4	42	1
	Iran	31	5	1	1	62
China		Russia	Saudi	Angola	Iran	Iraq
	Russia	69	6	1	21	3
	Saudi	17	66	1	15	1
	Angola	4	2	88	5	1
	Iran	8	5	1	84	2
	Iraq	10	5	5	23	57
Japan		Saudi	Qatar	Kuwait	Indonesia	Iran
	Saudi	85	1	1	9	4
	Qatar	7	89	2	1	1
	Kuwait	2	1	94	2	1
	Indonesia	13	1	3	82	1
	Iran	27	3	6	2	62
Korea		Saudi	Iraq	Kuwait	UAE	
	Saudi	85	2	5	8	
	Iraq	15	71	5	9	
	Kuwait	37	1	59	3	
	UAE	53	2	10	35	

Table 5
Volatility spillover – China (Panel a: Quantity; Panel b: Prices).

Panel a: Exporting countries	RUSSIA	SAUDI	ANGOLA	IRAN	IRAQ	D from O
RUSSIA	16.82	0.94	0.29	0.95	1.00	3.18
SAUDI	5.51	12.99	0.15	0.44	0.91	7.01
ANGOLA	1.42	1.13	16.06	0.23	1.16	3.94
IRAN	1.86	0.27	0.74	14.78	2.35	5.22
IRAQ	1.53	0.32	0.20	1.05	16.91	3.09
D to O	10.32	2.66	1.38	2.66	5.42	22.44
D to O + Own	27.15	15.65	17.44	17.44	22.33	100.00
					TSI	0.22
Panel b: Exporting countries	**RUSSIA**	**SAUDI**	**ANGOLA**	**IRAN**	**IRAQ**	**D from O**
RUSSIA	13.90	1.25	0.09	4.19	0.57	6.10
SAUDI	3.41	13.27	0.01	3.01	0.31	6.73
ANGOLA	0.90	0.31	17.66	1.05	0.08	2.34
IRAN	1.59	1.05	0.19	16.78	0.39	3.22
IRAQ	1.99	0.97	1.08	4.57	11.38	8.62
D to O	7.89	3.57	1.38	12.82	1.34	27.01
D to O + Own	21.79	16.84	19.04	29.60	12.73	100.00
					TSI	0.27

Table 6
Volatility spillover - Japan (Panel a: Quantity; Panel b: Prices).

Panel a: Exporting countries	SAUDI	QATAR	KUWAIT	INDONESIA	IRAN	D from O
SAUDI	17.67	0.37	0.04	0.90	1.01	2.33
QATAR	0.67	18.80	0.47	0.02	0.03	1.20
KUWAIT	0.32	0.00	19.57	0.04	0.07	0.43
INDONESIA	1.26	0.28	0.07	18.33	0.06	1.67
IRAN	5.50	0.77	0.63	0.92	12.17	7.83
D to O	7.75	1.43	1.22	1.88	1.18	13.45
D to O + Own	25.42	20.23	20.79	20.20	13.35	100.00
					TSI	0.13

Panel b: Exporting countries	SAUDI	QATAR	KUWAIT	INDONESIA	IRAN	D from O
SAUDI	17.05	0.27	0.14	1.84	0.71	2.95
QATAR	1.32	17.82	0.53	0.28	0.05	2.18
KUWAIT	0.45	0.18	18.86	0.48	0.03	1.14
INDONESIA	2.69	0.07	0.61	16.50	0.14	3.50
IRAN	5.51	0.60	1.19	0.36	12.34	7.66
D to O	9.96	1.12	2.46	2.96	0.92	17.43
D to O + Own	27.01	18.94	21.32	19.46	13.27	100.00
					TSI	0.17

Table 7
Volatility spillover - Korea (Panel a: Quantity; Panel b: Prices).

Panel a: Exporting countries	SAUDI	IRAQ	KUWAIT	UAE	D from O
SAUDI	24.32	0.41	0.01	0.26	0.68
IRAQ	3.21	21.15	0.15	0.50	3.85
KUWAIT	1.08	2.33	21.49	0.10	3.51
UAE	0.66	5.14	0.70	18.49	6.51
D to O	4.94	7.89	0.86	0.85	14.55
D to O + Own	29.26	29.04	22.35	19.35	100.00
				TSI	0.15

Panel b: Exporting countries	SAUDI	IRAQ	KUWAIT	UAE	D from O
SAUDI	21.24	0.57	1.22	1.96	3.76
IRAQ	3.65	17.90	1.27	2.18	7.10
KUWAIT	9.36	0.17	14.77	0.70	10.23
UAE	13.35	0.37	2.51	8.77	16.23
D to O	26.35	1.12	5.01	4.84	37.32
D to O + Own	47.60	19.02	19.78	13.60	100.00
				TSI	0.37

Table 8
Volatility spillover - Taiwan (Panel a: Quantity; Panel b: Prices).

Panel a: Exporting Countries	SAUDI	UAE	OMAN	IRAQ	IRAN	D from O
SAUDI	17.24	0.10	0.12	0.31	2.24	2.76
QATAR	0.13	18.38	0.62	0.17	0.70	1.62
KUWAIT	0.05	1.14	17.53	0.04	1.24	2.47
INDONESIA	0.24	0.34	0.05	19.21	0.16	0.79
IRAN	1.53	1.19	1.76	0.27	15.26	4.74
D to O	1.94	2.77	2.54	0.79	4.34	12.39
D to O + Own	19.18	21.15	20.07	19.99	19.60	100.00
						0.12

Panel b: Exporting Countries	SAUDI	UAE	OMAN	IRAQ	IRAN	D from O
SAUDI	19.14	0.44	0.01	0.04	0.38	0.86
QATAR	2.70	16.42	0.01	0.09	0.78	3.58
KUWAIT	5.52	0.33	13.76	0.36	0.02	6.24
INDONESIA	9.62	1.15	0.78	8.39	0.05	11.61
IRAN	6.26	1.00	0.17	0.16	12.41	7.59
D to O	24.10	2.92	0.97	0.65	1.22	29.87
D to O + Own	43.24	19.34	14.74	9.05	13.64	100.00
					TSI	0.30

four markets that come from spillovers.

Table 5 refers to volatility spillover among main Chinas' exporting countries; panel a refers to oil quantity and panel b refers to oil price. First of all, we can see that he total spillover from Russia to other countries account for 10.32%, meanwhile the spillover from other countries to Russia is 3.18%, this evidences that the any potential shock could trigger in Russia spilling over the rest of exporting countries. This

Table 9
Orthogonalized index (Quantity).

Exporting Countries	Importers	To	From	Net	Net transfer
RUSSIA	CHINA	10.32	3.18	7.15	Yes
SAUDI		2.66	7.01	−4.35	No
ANGOLA		1.38	3.94	−2.56	No
IRAN		2.66	5.22	−2.56	No
IRAQ		5.42	3.09	2.33	Yes
SAUDI	JAPAN	7.75	2.33	5.42	Yes
QATAR		1.43	1.20	0.23	Yes
KUWAIT		1.22	0.43	0.79	Yes
INDONESIA		1.88	1.67	0.20	Yes
IRAN		1.18	7.83	−6.65	No
SAUDI	KOREA	4.94	0.68	4.26	Yes
IRAQ		7.89	3.85	4.04	Yes
KUWAIT		0.86	3.51	−2.65	No
UAE		0.85	6.51	−5.65	No
SAUDI	TAIWAN	1.94	2.76	−0.82	No
QATAR		2.77	1.62	1.15	Yes
KUWAIT		2.54	2.47	0.07	Yes
INDONESIA		0.79	0.79	−0.01	No
IRAN		4.34	4.74	−0.40	No

Table 10
Orthogonalized index (Price).

Exporting Countries	Importers	To	From	Net	Net transfer
RUSSIA	CHINA	7.89	6.10	1.79	Yes
SAUDI		3.57	6.73	−3.16	No
ANGOLA		1.38	2.34	−0.96	No
IRAN		12.82	3.22	9.60	Yes
IRAQ		1.34	8.62	−7.27	No
SAUDI	JAPAN	9.96	2.95	7.01	Yes
QATAR		1.12	2.18	−1.06	No
KUWAIT		2.46	1.14	1.32	Yes
INDONESIA		2.96	3.50	−0.54	No
IRAN		0.92	7.66	−6.73	No
SAUDI	KOREA	26.35	3.76	22.60	Yes
IRAQ		1.12	7.10	−5.98	No
KUWAIT		5.01	10.23	−5.22	No
UAE		4.84	16.23	−11.40	No
SAUDI	TAIWA N	24.10	0.86	23.24	Yes
QATAR		2.92	3.58	−0.66	No
KUWAIT		0.97	6.24	−5.26	No
INDONESIA		0.65	11.61	−10.95	No
IRAN		1.22	7.59	−6.36	No

is particularly true for quantity meanwhile in term of prices the difference is smaller. In term of quantity the opposite is true for Saudi that contributes to the rest of countries for 2.66% receiving form others 7.01%. The same picture arises for Angola and Iran meanwhile Iraq repurposes the same relationship between the two streams of spillovers seen for the United States. Moving to the panel b the "input-output" scenario for the decomposition of volatility is quite different.

The magnitude of streams of spillovers from e to Russia are comparable lying between 6.1 and 7.89%. Saudi confirms that others countries spill on Saudi (6.73%) twice than Saudi spill to theme (3.57%). The same scenario arises from Iraq with the "from others" spill that is less than one third of the "to others" stream. Iran is characterized by an opposite situation given that it contributes to others with 12.82% receiving less than 3.22%.

The TSI ranges from 22% to 27% meaning that this is the portion of the forecast error variance coming from spillovers in returns. Japan (Table 6) shows a different structure of volatility across its main oil producers that are different from Russians' exporting countries.

Firstly, TSI for Japan is smaller than the index computed for all other countries. Oil quantity TSI is equal to 13% and oil price TSI is equal to 17%. This means that portion of the forecast error variance error coming from spillovers in returns, is relatively marginal.

Among Japan's supplying countries only Saudi and Iran show a substantial unbalance between "from" and "to" others with symmetric behavior. Indeed, if we refer to quantity Saudi spill to others 7.75% receiving 2.33% meanwhile other countries spill to Iran for 7.83% receiving 1.18%. A similar figure characterizes price volatility. Volatility associated to oil quantity exchanged, streams from Saudi and Iraq to UAE and Kuwait among Koreans' suppliers (Table 7) in term of quantity, but Iraq reverse its position if we refer to price volatility leaving Saudi as net transfer country Oil quantity TSI for Korea is small (15%) and comparable to Japan index but oil price TSI is equal to 37% that is the higher value computed in our sample.

This means that portion of the forecast error variance error coming from spillovers in returns, is important among Japan's oil suppliers. Taiwan TSI values (Table 8) are really closed to Koreans' ones. Spillovers account for more than 30% in term of price volatility but the share falls to 12% referring to the quantity volatility. Main contributor is the Saudi that spill to other countries for 19.2% in terms of quantity volatility and for 24.1% in term of price volatility.

Finally, Tables 9 and 10 show net contributors for both kind of volatility.

Among the main exporting countries, Saudi is the only country that exports oil in all the countries analyzed and it always is a "net transfer" except of for Taiwan.

Kuwait exports oil in three out of four countries maintaining the role of "net transfer" in Taiwan and in Japan. Russia acts as net transmitter in China market while Iran is always a net receiver.

The higher magnitude in the "net transfer" belong to Russia while the higher magnitude associated to net receiver countries refers to Iran in Japanese oil market.

Focusing on price volatility (Table 10) the number of net transfers decrease substantially. Saudi is still the most important net transmitter in "three markets": Japan, Korea and Taiwan. Iran becomes net transmitter in Chinese oil market remaining net receiver in others two markets (Taiwan and Japan). Referring to the price volatility the higher magnitude in the "net transfer" belong to Saudi both in the Korean and Taiwan market with 22.60% and 23.4% respectively. Most important net receivers are UEA (−11.4%) in Korean' market and Indonesia (−10.95%) in the Taiwan oil market.

4.3. Simulation of scenarios

We develop two scenarios to assess potential impacts on the importers' portfolios resulting from the changes in portfolio structure, geopolitical events and disruptions due to pandemic scenario. To assess the impact of the scenarios, we use a Baseline scenario to characterize the optimal position of each country on its efficient frontier, using the average monthly oil imports data observed in the most recent year of the estimation sample. Table 11 describes the scenarios. The first scenario "Covid-19 Shock" is constructed to represent the immediate effect of the Covid-19 shock, assuming a sharp reduction of the import quantities by 20% in China and 15% on other countries. To support this scenario, we use recent reports of May 2020 (OilPrice, 2020; IEA, 2020) to assess that China's oil demand decreased by around 20% at the top of the crisis and is returning almost to normal in the second quarter 2020. Also, in Japan global fuel demand is forecasted to decline around 15% in the second quarter 2020.

The second scenario "Increased Imports from KSA" allows to analyze the impact of reallocation of shares among oil supplier on each importing country's portfolio. This scenario assumes a return to normal import levels to each country. Given the higher flexibility of the Saudi oil system, we assume that the return to normal is characterized by a portfolio restructuring of each country by increasing the share of oil imports from Saudi Arabia. We apply a 10% increase of the Saudi share in each country's portfolio assuming that Saudi Arabia may be the country that benefits the most from the world recovery. In other words, this is accomplished simulating an increase of 10% of the share of Saudi Arabia in each of the four importers' portfolios w.r.t the Baseline 2017 – amounting to approximately additional 1.5 million tons per month for the four importers. The results of the scenario simulations are summarized in Tables 12 and 15. Regarding the first scenario, the outcomes of the Covid-19 disruptions also vary significantly for all countries. In Table 12 we report only the effect on the import growth rate, because we cannot assess in plausible manner the effect on prices.

In this case, the volatility of oil imports portfolio increases within the range of 3% for Taiwan to 8–9% for the major countries – China and Japan – 15% for Korea.

Focusing on spillovers composition, the scenario effects are evaluated using both the TSI, that summarizes the total of non-directional volatility spillover into a single index and the change in contributors' profile, which captures the change in the number of eligible countries as net contributors to volatility. TSI shows on average, across our entire sample, the percentage of volatility forecast error variance that arises from spillovers and in the first scenario we can see that TSI substantially increases among four countries (Table 13).

This generalized increase is also associated with important changes in the spill-overs composition, for at least 60% of exporting countries change their "net transfer" status. For example, all Korea exporting countries modify their status both for quantity and prices. Regarding the second scenario, different oil import portfolios structures yield significant variations in the results.

We report for a given growth rate the implied change in the optimal associated risk measure in Table 14.

We note that more concentration can imply can positive beneficial and detrimental impact. In practice, higher concentration has a negative effect in terms of increasing volatilities for the growth rate of oil import

Table 11
Description of energy security scenarios for oil importers.

Scenario	Description
Baseline 2017	We take the point on the efficient frontier curves for each oil importing country (China, Japan, Korea and Taiwan), corresponding to the most recent observed average monthly oil import volumes growth rates and oil import price benefit.
Covid-19 Shock (temporary worldwide demand shock)	We assume a temporary reduction of oil import volumes by 20% in China and 15% in other countries.
Increased Imports from KSA	We increase the share of oil imports from Saudi Arabia by 10% for each economy. Imports from other suppliers are proportionally reduced, so that the total import volumes remain the same.

Table 12
Scenario Covid-19 shock. Effects of temporary oil import reduction.

Importer	Parameter	Baseline 2017	Covid-19 shock	
		Values	Values	% Change
China (volume)	Growth rate	1.22	1.02	−20%
	St. dev.	0.055	0.0594	8.0%
Japan (volume)	Growth rate	1.17	1.02	−15%
	St. dev.	0.67	0.73	9.0%
Korea (volume)	Growth rate	0.26	0.11	−15%
	St. dev.	0.53	0.61	15.1%
Taiwan (volume)	Growth rate	4.37	4.22	−15%
	St. dev.	0.798	0.822	3.0%

Table 13
Scenario Covid-19 shock. Effects of temporary spill-over change.

Import country	Baseline	Covid-19	% TSI change	Change in contributors profile[a]
China Q	0.22	0.30	0.32	60%
China P	0.27	0.32	0.18	60%
Japan Q	0.13	0.15	0.12	80%
Japan P	0.17	0.15	−0.14	60%
Korea Q	0.15	0.20	0.28	100%
Korea P	0.37	0.38	0.02	100%
Taiwan Q	0.12	0.10	−0.19	60%
Taiwan P	0.30	0.31	0.03	80%

[a] Computed as # of countries that change out of # total exporting countries.

Table 14
Scenario Increased imports from KSA. Effects of increased oil imports from Saudi Arabia.

Importer	Parameter	Baseline 2017	Increased KSA imports	
		Values	Values	% Change
China (volume)	Growth rate	1.22	1.22	
	St. dev.	0.055	0.0667	21.3%
China (price)	Price benefit	650.8	657.5	1.0%
	St. dev.	352.0	342.1	−2.8%
Japan (volume)	Growth rate	1.17	1.17	
	St. dev.	0.67	0.797	19.0%
Japan (price)	Price benefit	597.6	597.5	0.0%
	St. dev.	429.8	511.6	19.0%
Korea (volume)	Growth rate	0.26	0.26	
	St. dev.	0.53	0.647	22.1%
Korea (price)	Price benefit	603.3	607.5	0.7%
	St. dev.	262.9	324.2	23.3%
Taiwan (volume)	Growth rate	4.37	4.37	
	St. dev.	0.798	1.397	75.1%
Taiwan (price)	Price benefit	610.2	606.4	−0.6%
	St. dev.	272.1	367.4	35.0%

Table 15
Scenario Increased imports from KSA. Effects of temporary spill-over change.

Import country	Baseline	Import KSA	% TSI change	Change in contributors profile[a]
China Q	0.22	0.16	−0.34	60%
China P	0.27	0.45	0.52	60%
Japan Q	0.13	0.12	−0.04	60%
Japan P	0.17	0.16	−0.08	80%
Korea Q	0.15	0.14	−0.04	1%
Korea P	0.37	0.68	0.61	1%
Taiwan Q	0.12	0.07	−0.54	80%
Taiwan P	0.30	0.31	0.03	60%

[a] Computed as # of countries that change out of # total exporting countries.

volumes for all countries and also the average import price for Japan and Korea. On the contrary, the effect on the import price is beneficial (reduction of volatility) for China and Taiwan.

We note that for the second scenario, the price spillover levels are generally higher and increasing. (Table 15).

The increase appears to be stronger for Korea and China than for the other countries. Quantity are associated with more contained variation even if the net transfer status changes consistently among exporting countries also in this scenario, confirming the existence of important reallocation effects.

4.4. Discussion

This paper analyzes the oil imports structure of four major Asian energy importers: China, Japan, Korea and Taiwan, investigating the risk associated with the portfolio composition of the suppliers. When a country faces a portfolio of suppliers to satisfy her energy needs it has to define the composition of its portfolio in order to choose the optimal risk-return combination. The implicit assumption is that each country values its energy security in economic terms, considering a two-dimensional measure associated to its portfolio of oil suppliers: the total imports growth rate and the average import price. Further, we investigate the interdependence of the volatility spread among countries using TSI in a framework of volatility interdependence of suppliers' portfolio. The proportion of a shock from one country that spills over to another country or group of countries is computed.

We find that the TSI is lower for quantity than for prices, but nonetheless the values are around 25–30%, generally lower than results typically reported for financial markets. This can be interpreted as an indication that, despite the fact that the oil market is considered a global market, a significant proportion of volatility is due to intrinsic factors and shocks that are specific to individual countries.

Also, we note that Saudi Index Direction to Other is always lower that the index Direction from Other. We interpret this as an indication that Saudi Arabia is not so actively influencing the market, but rather absorbs shocks from others. This is in line with the official declaration mode of the Saudi oil authorities who have always refused to be considered market-makers (in the words of HRH Prince Abdulaziz bin Salman Al Saud; Saudi Minister of Energy: We act to "enhance oil market stability, help accelerate the rebalancing of global oil markets and send a constructive signal to the market (SPA, 2020).

Turning the attention to the direction of volatility spillovers, we find that Saudi Arabia, Russia and Iran can be viewed as the major volatility spillover transmitters and receivers in all four importers. This is not surprising, suggesting a behavior of higher influence to other suppliers.

Interestingly, we note that Russia is a net spillover transmitter in the China market, and Saudi Arabia is a net transmitter in the Japan market, indicating that these two exporters do influence other suppliers in the main Asian economy's markets.

In net terms, the results confirm that the net direction of spillover effects are different in different markets. It is evident the case of Saudi Arabia, which has a net index higher in Japan and Korea and lower in China and Taiwan, this can be interpreted as a closer interconnection of the Saudi with the older manufacturers of Asia.

The results of the scenario simulations highlight that China rapidly return almost to normal in the second quarter 2020, despite the Covid-19 impact. In other countries the outcomes of the Covid-19 disruptions are highly heterogeneous and the adjustment paths are different in term of time required. This is a confirmation of the flexibility of the productive structure of the Chinese industry. The China's official manufacturing purchasing managers' index jumped 51.5% in September 2020 according to the data released by the National Bureau of Statistics (NBS, 2020).

The analysis of the impact of reallocation of shares among oil supplier on each importing country's portfolio is conducted in the second scenario that assumes a return to normal import levels to each country. Given the higher flexibility of the Saudi oil system, we assume that the return to normal is characterized by a portfolio restructuring of each country by 10% increasing the share of oil imports from Saudi Arabia. In this scenario the price spillover levels are generally higher and increasing if compared to Covid-19 scenario. This can be interpreted as an indication that the Saudi's strategy of reallocation can have deeper effects on the markets than an unexpected shock (like the Chinese slowdown due to the Covid pandemic), possibly increasing the degree of risk aversion of the market participants in the oil market. This is a relevant information for policy-making, because changes in the risk perception in the market calls for more attention to foster resilience, to promote adaptability and to reduce the intrinsic weakness of the market functioning, ideally strengthening international policy coordination.

5. Conclusions

We have investigated new developments of the concept of energy security, acknowledging that security of physical supply and price affordability are the main corner stones. The recent developments of the energy markets and the new globalization and geopolitical trends suggest that there is need to include an evaluation of the risk dimension in economic terms.

In this paper we have proposed a joint measure of the risk-return trade-off, viewed from the perspective of a single oil importer, which entertains bilateral relationships with a group of suppliers. In this view, there is the need to construct a portfolio of suppliers and to assess the impacts of potential vulnerabilities.

This paper shows a practical application of the financial portfolio theory to the energy security domain, by estimating efficient frontiers of oil imports and their prices for the major Asian energy importers and estimating a new measure of risk volatility and associated spillover effects.

We estimate the efficient frontiers for China, Japan, Korea and Taiwan, offering a measure of the risk levels associated with a portfolio composition, which is necessary to achieve a given level of total oil import growth and average oil import prices. In addition, we have shown a mew measure of risk volatility of the composition of imports and a new measure of directional spillover that sheds light on the cross-volatility transmission of different suppliers to a given country.

In conclusion, we offer a scenario analysis of the possible effects of the Covid-19 shock and of a potential increase of Saudi Arabia share in each country' s portfolio of suppliers.

In the first case, the short-run portfolio risk increases across the board, albeit at different rates: from 3% for Taiwan to 15% for Korea.

In the second case, we note that with the increasing share of oil imports from the most reliable and stable suppliers (Saudi Arabia), the optimal risk in the portfolio increases. The spillover effects are increasing as expected. The spillover analysis shows a consistent reallocation effects among spillover directions together with their generalized increase. This confirms that a deep shock can modify the quality composition of the variance and not only its level.

CRediT authorship contribution statement

Simona Bigerna: Conceptualization, Methodology, Software, Data curation, Writing - original draft. **Carlo Andrea Bollino:** Conceptualization, Methodology, Software, Data curation, Writing - original draft. **Paolo Polinori:** Conceptualization, Methodology, Software, Data curation, Writing - original draft.

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